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ADVANCED INTERACTIVE DISPLAY FORMATS FOR TERMINAL AREA TRAFFIC CONTROL

A Joint Research Project Between NASA Ames Research Center, Moffett Field, Ca, and The Faculty of Aerospace Engineering at the Technion, Israel Institute Of Technology, Haifa, Israel

Semiannual Report

Cooperative Grant No.: NCCW-0045

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Progress report for the period: October 1, 1994 - March 31, 1995

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PREFACE

This report describes a continuing cooperative research effort between NASA Ames Research Center and the Faculty of Aerospace Engineering, Technion, Haifa, Israel, in the area of advanced pictorial displays for aerospace applications. The efforts will be focused on the development of advanced display formats for Center-TRACON Air Traffic Control displays. This progress report describes the basic principles and software developments for manual viewing parameter setting in perspective Air Traffic Control Displays. Subsequent developments will, among others, deal with automated viewing parameter setting according to a well-chosen optimization strategy.

ABSTRACT

This report describes the basic design considerations for perspective Air Traffic Control displays. A software framework has been developed for manual viewing parameter setting (MVPS) in preparation for continued, ongoing developments on automated viewing parameter setting (AVPS) schemes. The MVPS system is based on *indirect* manipulation of the viewing parameters. Requests for changes in viewing parameter setting are entered manually by the operator by moving viewing parameter manipulation pointers on the screen. The motion of these pointers, which are an integral part of the 3-D scene, is limited to the boundaries of screen. This arrangement has been chosen, in order to preserve the correspondence between the new and the old viewing parameter setting, a feature which contributes to preventing spatial disorientation of the operator. For all viewing operations, e.g. rotation, translation and ranging, the actual change is executed automatically by the system, through gradual transitions with an exponentially damped, sinusoidal velocity profile, in this work referred to as 'slewing' motions. The slewing functions, which eliminate discontinuities in the viewing parameter changes, are designed primarily for enhancing the operator's impression that he, or she, is dealing with an actually existing physical system, rather than an abstract computer-generated scene. Current, ongoing efforts deal with the development of automated viewing parameter setting schemes. These schemes employ an optimization strategy, aimed at identifying the best possible vantage point, from which the Air Traffic Control scene can be viewed, for a given traffic situation.

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BACKGROUND

1.1. Focus of Interest of this Research

Increasing the Terminal Area Productivity involves increasing the number of aircraft in the terminal area, decreasing the minimal separation distance between aircraft and minimizing the delays. This might involve the use of complex, curved approach trajectories with a build-in flexibility to introduce fast, dynamic changes, where all operations in this environment are subject to stringent safety requirements.

The increased productivity will also involve increased interaction with each one of the aircraft in the area, and consequently, will result in increased task complexity of the Air Traffic Controller. Although automated sequencing, scheduling and route generation optimization tools are vital attributes in this complex environment, this research is focused on the Human Controller Interface. This interface must allow the controller to monitor, manage and control this complex environment through effective interaction with the automated system.

1.2. 'Conventional' Plan View Displays vs. Perspective Displays

Air Traffic Control Displays conventionally represent a plan view of the Air Traffic area. The advantage of this approach is that the interpretation of the ground-track aircraft positions is straight-forward and all viewed areas in the arena are 'weighted' with equal importance. On the other hand, perspective displays present the view of a 3-D scene from a well chosen vantage point, and thus integrate the horizontal situation with altitude separation by visualizing the 4-D (Spatial position + velocity) trajectories and constraints in one perspective format. Thus perspective displays offer the advantage that the altitudes of the aircraft, which in the conventional format were represented by data tags, are inherently present in the perspective scene. Thus, two aircraft with nearby ground-track positions, but separated in altitude, will appear 'clustered' on the plan view display, but will appear clearly separated on the perspective display.

In addition to this advantage, the third dimension in perspective displays offer the option of more easy and effective three-dimensional routing, for example, in situations where an upcoming weather front demands re-routing of the traffic flow, or when due to exceptional back-up or emergencies a feeder gate is being closed.

Possible disadvantages of perspective Air Traffic Control displays are: (1) fast and/or badly designed viewing parameters operations might lead to disorientation of the operator, or impair the operator's spatial awareness, which is a vital attribute in Air Traffic Control tasks; (2) the estimation of relative orientation between objects in the three-dimensional field from perspective views, might be subject to inherent systematic errors, as shown in earlier work[1] ; (3) an incorrectly chosen viewpoint might result in clutter, exclusion of aircraft symbols from the view, or ambiguities in determining spatial positions; (4) the perspective view inherently biases the allocation of attention to nearby, centrally viewed areas, on the account of far-away areas in the periphery; (5) perspective displays, based on single-width, single intensity monochrome wire-frame graphics, might have ambiguities in their spatial representation, e.g. the 'Necker' cube effect, or the well-known 'inverse depth cueing' effects due to clustering of lines at far-away distances.

In order to be able to utilize the full potential of perspective displays and to avoid the above mentioned possible disadvantages, effective and well-designed viewing parameter manipulations are essential. Carefully controlled and well chosen viewing parameters can eliminate the potential disadvantages (1) to (3), whereas automated, optimizing viewing parameter setting schemes might direct the operator's attention to critical areas, thus turning disadvantage (4) into an advantage. Furthermore, up-to-date real-time computer graphics technology such as solid modeling, texture mapping, shading and alpha blending (realizing semi-transparent surfaces) are able to generate impressively realistic scenes with sufficient update rate, which almost entirely eliminate disadvantage (5).

1.2. The Purpose of the Research

The purpose of the research is to find the basic rules and techniques for utilizing the full potential of perspective displays for Air Traffic Control. The display should allow manual and computer-aided traffic flow management and 4-D path planning. The display should enable the operator a clear and unambiguous assessment of the 3-D traffic situation. An essential aspect of the problem is the development of manual and automated viewing parameter manipulations, which enable to utilize the 3-D potential of the perspective display to the full extent, while avoiding the possible disadvantages. In this progress report the basic principles and software developments for manual viewing parameter setting in perspective Air Traffic Control Displays are described, and ongoing efforts for automated viewing parameter setting, are outlined.

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[1] Grunwald, A.J., Ellis, S.R. and Smith, S., "A Mathematical Model for Spatial Orientation from Pictorial Perspective Displays," IEEE Trans. on SMC, Vol. 18, No. 3, May, June 1988, pp. 425-437.

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BASIC DESIGN CONSIDERATIONS

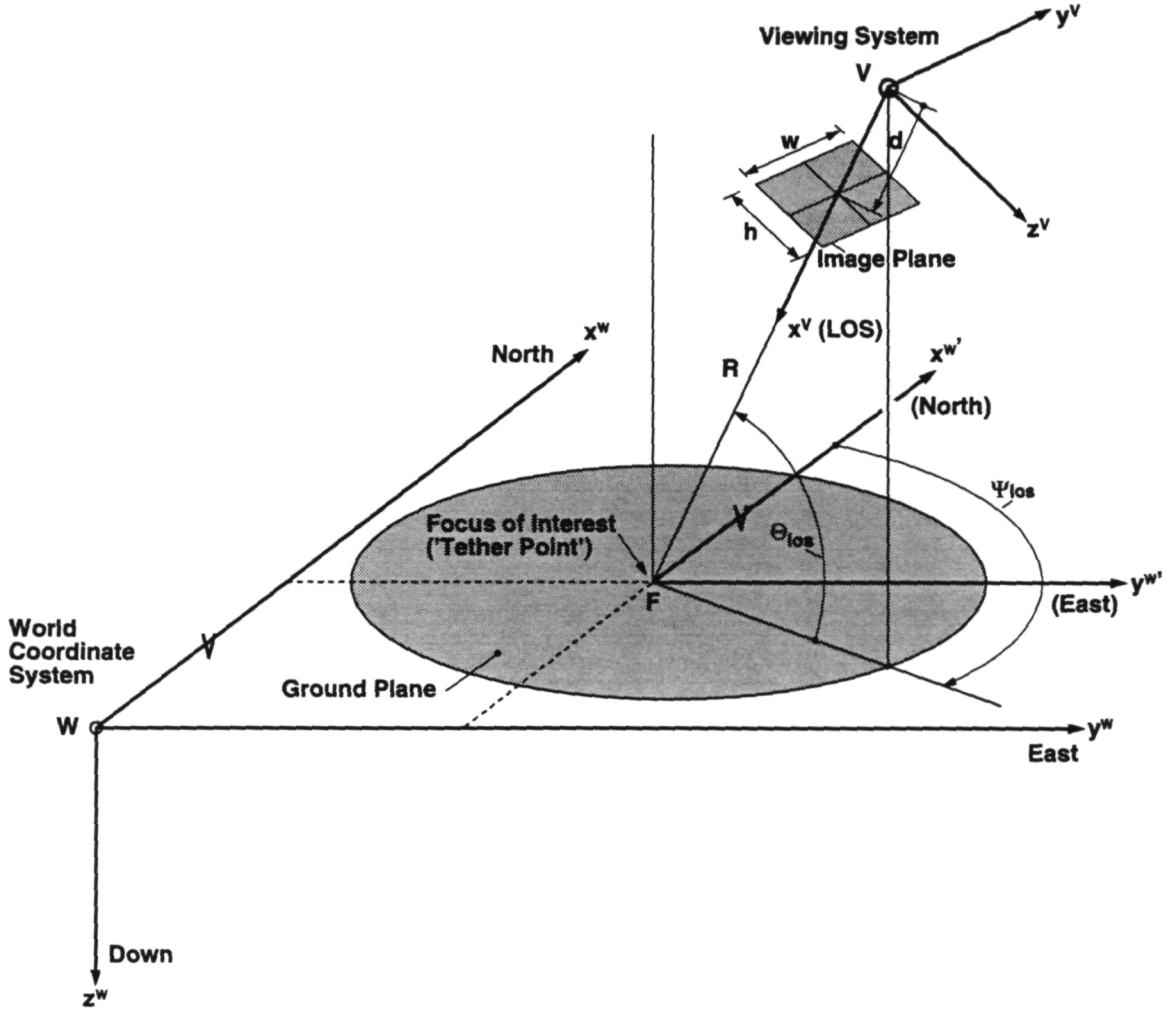

Figure 1.: Viewing situation geometry

2.1. Definition of Coordinate Systems

The Air traffic Control scene is described in a world coordinate system W, with the x^W-axis pointing to the north, the y^W-axis to the east and the z^W-axis downwards. The origin of this system, W, is placed at a fixed reference location, such as an ILS/VOR station at the central airport. For low-altitude displays, the 3-D terrain features, like mountains, obstacles, etc., should be modeled as well. For high-altitude displays, the 3-D terrain features are less important and the terrain can be modeled as a 'flat' texture map.

A viewing system V is defined with the viewer's eye point at the origin and the x^V-axis being the line-of-sight, or viewing axis. The y^V- and z^V-axes are pointing to the right and downwards, respectively, see Fig. 1. The perspective scene is projected on an image plane in front of the viewer. The height h and width w, and distance of this image plane from the viewer's eye, d, determine the horizontal and vertical field-of-view. In this case, the image plane is the monitor screen. For correct viewing, the eye should be positioned at the viewing system's origin V (the 'station point'). However, for the usual dimensions of the monitor screen and the average distance from which the screen is viewed, the field-of-view angles might not be large enough for sufficient coverage of the scene. In this case, the station point will be closer to the screen than the actual eye position.

2.2. Basic Viewing Parameters

The viewing parameters include the $x^W y^W z^W$ coordinates of the viewing system origin V in the world coordinate system W, the yaw, pitch and roll Euler angles, ψ, θ, ϕ, which determine the angular orientation of the viewing system V with respect to the world coordinate system W, the dimensions h and w, and the distance d of the image plane from the viewer's eye. Since the dimensions of the image plane are determined by the dimensions of the screen, in the case the full screen area is used, or the dimensions of a viewport, in the case only part of the screen is used, this leaves 7 independent viewing parameters. Since control over each one of these 7 viewing parameters is impractical, it is necessary to constrain the viewing operations to predetermined patterns.

2.3. Constraint Viewing Operations

The pattern, chosen for the Air Traffic Control scene, is the 'tethered' viewpoint control, shown in Fig. 1. A 'focus of interest' is defined in the ground plane. By 'tethering' the viewpoint V around this point, the viewing axis, or Line-of-Sight (LOS), remains at all times directed towards the focus of interest. Furthermore, by choosing both the base of the image plane and the y^V axis to be parallel to the ground plane, the roll-angle ϕ will remain zero, and the horizon will appear at all times as a horizontal line on the display.

The tethered viewing parameter setting is accomplished in three independent operations: (1) *translation* of the focus of interest in the ground plane; (2) *rotation* of the viewing axis by the azimuth angle[2] Ψ_{los} and the elevation angle Θ_{los}; (3) *ranging*, which is the displacement of the viewpoint along the viewing axis.

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[2]Note that the azimuth angle of the actual viewing direction is: $\Psi_{los} + 180^0$.

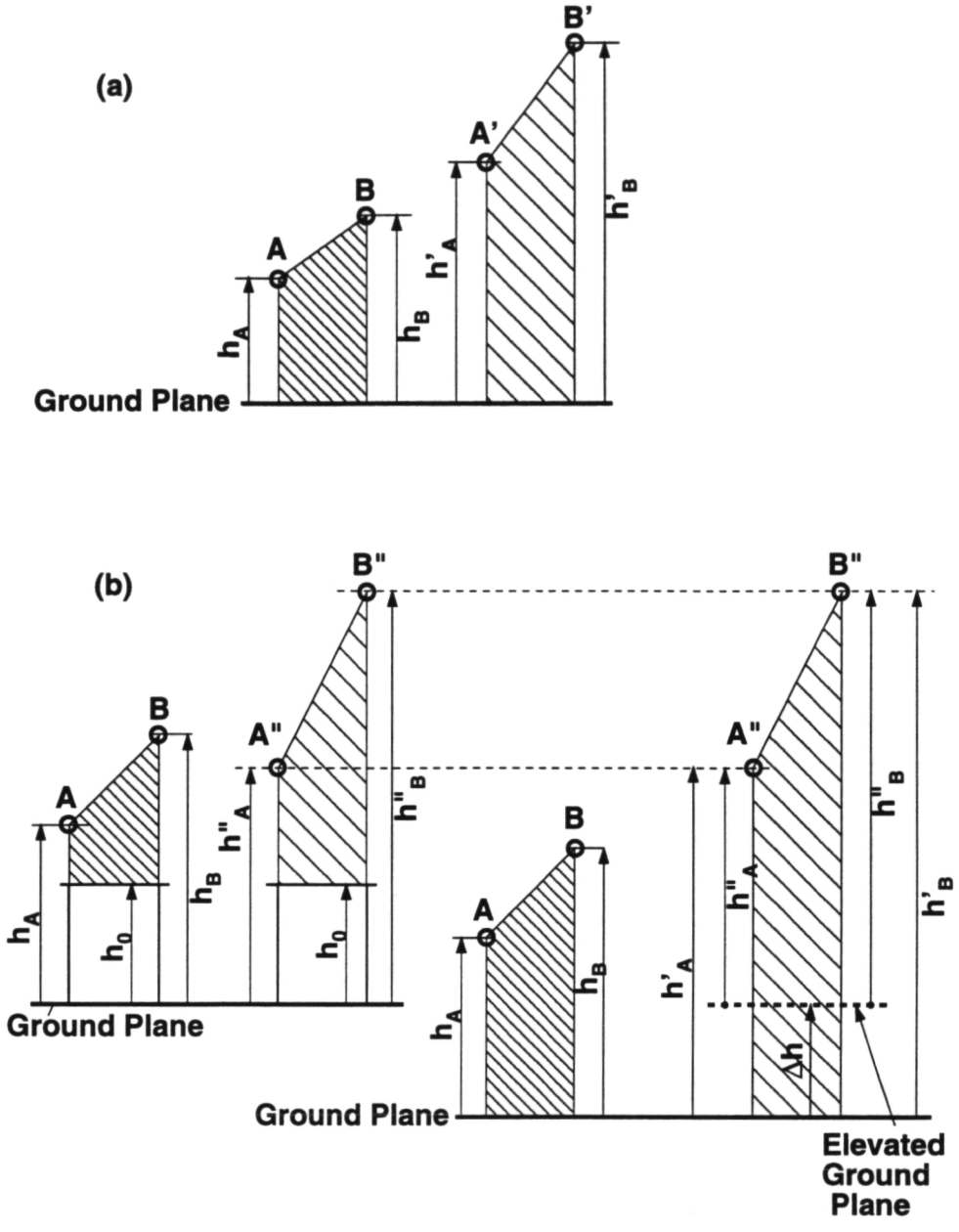

Figure 2.: Concept of enlargement of vertical scaling; (a) enlargement centered at height zero; (b) enlargement centered at height h_0

The ranging operation will allow areas of interest to be studied from close-by. The effect of this operation is similar to a 'zooming' operation of a camera, in the sense that, in both cases, areas of interest are enlarged. However, a zooming operation is achieved by changing the distance d of the image plane from the viewer's eye, while keeping the screen dimensions and the viewing range the same.

Since for large zoom angles and a flat image plane, the image will appear distorted, a ranging operation, rather than a zooming operation has been chosen. Consequently, a fixed value of d was used, so that viewing operations involve a total of only 5 viewing parameters to be set.

2.4. Segregated Control

The three viewing operations are executed separately and sequentially. Since the effects of the operations are isolated from each other, it will make the viewing parameter change more easy understood and decrease the chance for disorientation.

2.5. Indirect Manipulation

The viewing parameter operations are chosen to be performed in an *indirect* mode. In this mode, the operator first introduces a requested change in the viewing parameters. After the requested change has been entered, the actual changes are made automatically by the system, through a controlled slewing motion. This method is basically different from a *direct mode*, in which the viewing parameters are linked directly to the control manipulators, as if flying an aircraft.

2.6. Enlargement of Vertical Scaling

Enlarged vertical scaling is commonly used in relief maps, with the purpose of enhancing the 3-D features of the terrain. The amount of 'exaggeration' usually depends on the features which the map designer would like to emphasize. In the perspective Air Traffic Control display, the enlargement in vertical scaling should be chosen in accordance with the smallest scale, which still allows a relevant minimal vertical separation distance to be detected by the operator. However, for high-altitude displays this enlarged scaling might result in the ground plane being out of the visible range. In this case it might be necessary to 'center' the enlargement about a given fixed reference height, h_0, different from zero.

This concept is demonstrated in Fig. 2. Fig. 2a shows an enlargement of the vertical scale by the factor f, which is centered at the ground plane. After the enlargement, aircraft A and B will be at A' and B', respectively. The 'new' heights are given by:

$$h'_A = f h_A$$

$$h'_B = f h_B \qquad (1)$$

However, the new heights h'_A and h'_B might be so large, that the ground plane is no longer within the visible range. In Fig. 2b the enlargement is centered at height h_0. It is clear from this figure that the heights are now:

$$h''_A = f(h_A - h_0) + h_0 = h'_A - (f-1)h_0$$
$$h''_B = f(h_B - h_0) + h_0 = h'_B - (f-1)h_0 \qquad (2)$$

The second method is equivalent to a ground plane-centered enlargement of the vertical scaling by the factor f, while at the same time raising the ground plane by the amount:

$$\Delta h = (f-1)h_0 \qquad (3)$$

The factor f should be chosen in accordance with the demands for detecting minimal separations, whereas the height h_0 should be chosen such, that the ground plane will be within the visible range. It is clear that in the presence of 3-D terrain features in low-altitude displays, the parameter h_0 must be chosen zero. In all cases f *and* h_0 should be kept fixed during operations.

2.7. One-Control button Operation With 2-D Analog Device

In order to minimize the number of controls and to simplify system operations, all operations are performed with a standard 2-D analog device, with only one active button. Rather than using a multitude of control buttons, the screen cursor is used to select and activate the various attributes on the screen. The options are context sensitive, which means that the appearance of the relevant screen attributes and the control over these attributes, is restricted to the mode of operation the system resides in. This simplifies the selection and eliminates the need for multiple control buttons. In this case a three-button mouse is used as input device. Only the right mouse button is active. The term 'mouse button' as used hereafter, refers to the right mouse button.

Analog control devices are limited to a single 2-D mouse or tracking ball input device. The 2-D control inputs are slaved to the motions of a 2-D screen cursor, where the control gearing is chosen to be fixed. When in an active mode, the screen cursor is visible at all times and its motions are unconstrained. The screen cursor is used to relocate manipulation pointers, which, for example, introduce viewing parameter changes, in 3-D space. However, in contrast to the screen cursor, the motions of these pointers are constrained to their allowed degrees-of-freedom.

3

VIEWING PARAMETER OPERATIONS

3.1. Viewing Parameter Changes Through Slewing Motions

Since discontinuities in the setting of viewing parameters do impair the operator's ability for spatial orientation, all viewing parameter changes are made by means of gradual transitions, which are continuous in rate and acceleration. The time functions, which enable these gradual and smooth transitions are hereafter referred to as 'slewing functions'. Although the term 'slewing' is generally used for pivoting motion, like the rotation of a camera, in this report this term is used for all operations, e.g. rotation, translation and ranging.

3.2. Mathematical Formulation

Thus, all changes in the viewing parameters, are made according to an exponentially damped, sinusoidal slewing profile, in which the onset and offset of velocity are gradual, and the velocity is the largest midway. This profile is actually modeled after the time-response of a second-order, under damped system to a step input. Assume that a given viewing system parameter $x(t)$ is being modified. The actual path between the initial setting x_{old} and the final setting x_{new} is linear, and is given by:

$$x(t) = x_{old} + c(t)(x_{new} - x_{old}) \tag{4}$$

where $c(t)$ is a slewing function, varying between 0 and 1 and given by the following function of the time t:

$$c(t) = \frac{f(t)}{f_{\max}} \tag{5}$$

and $f(t)$ is the time response of a second-order system, with a unity DC gain, following a unity step input, according to:

$$f(t) = 1 - \frac{e^{-\pi \frac{t}{T_{slew}} \tan\phi}}{\sqrt{1-\zeta^2}} \cos\left(\pi \frac{t}{T_{slew}} - \phi\right) \tag{6}$$

and $f_{\max}$ is the peak value of $f(t)$, occurring at $t = T_{slew}$, given by:

$$f_{\max} = \left(1 + e^{-\pi \tan\phi}\right) \tag{7}$$

The angle ϕ is a phase shift angle due to damping and is defined as:

$$\phi = \tan^{-1}\left(\frac{\varsigma}{\sqrt{1-\varsigma^2}}\right) \tag{8}$$

where the parameter ς is the damping factor, $0 < \varsigma < 1$. The parameter T_{slew} is the 'slewing time', which is defined as the total time needed to complete the transition. It is also half of the period of the damped natural frequency ω_d:

$$T_{slew} = 0.5\omega_d; \quad \omega_d = \omega_0\sqrt{1-\varsigma^2} \tag{9}$$

where ω_0 is the undamped natural frequency. Note that $c(0) = 0$ and $c(T_{slew}) = 1$. Following Eq.(4) this means that at the start of the slewing action $x(0) = x_{old}$ and at the end $x(T_{slew}) = x_{new}$.

The slew-rate $\dot{f}(t)$ is obtained by differentiating Eq. (6):

$$\dot{f}(t) = \frac{\pi}{T_{slew}} e^{-\pi\frac{t}{T_{slew}}\tan\phi} \sin\left(\pi\frac{t}{T_{slew}}\right) \tag{10}$$

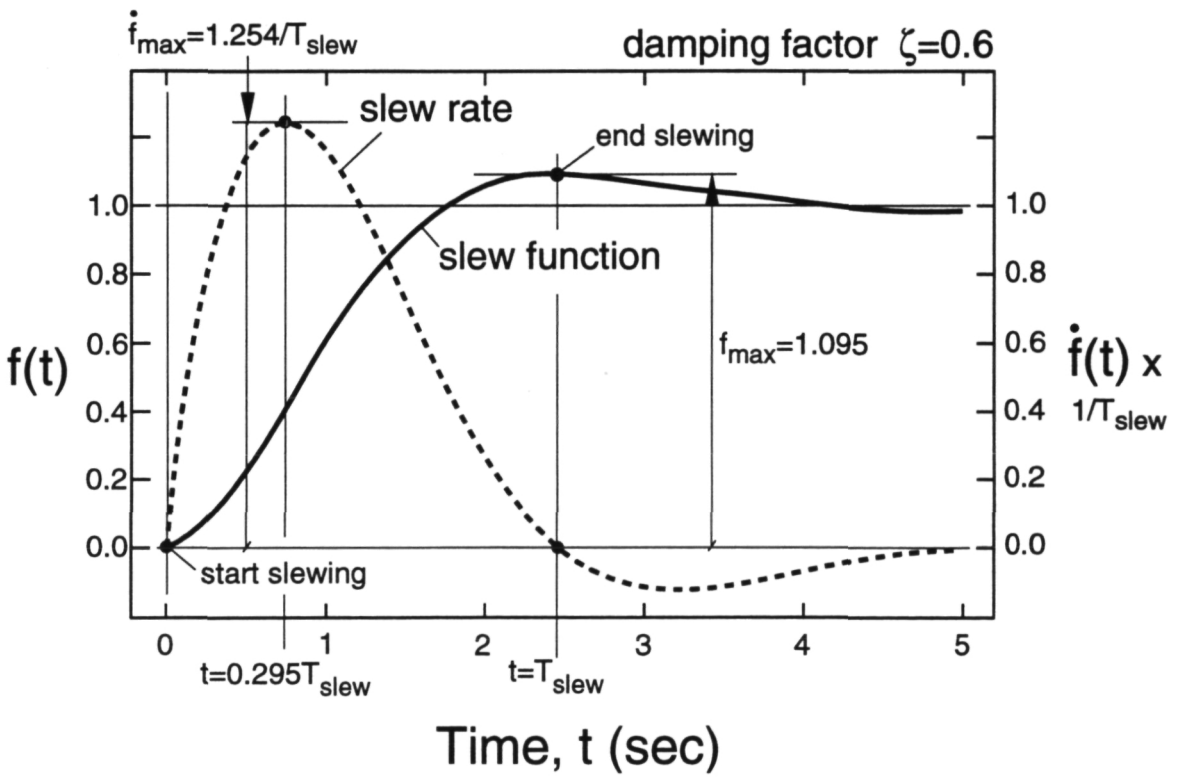

Figure 3.: Time histories of slew function and slew rate for $\zeta = 0.6$

The exponential term in Eq. (10) shows that the parameter ς causes an asymmetrical slew-rate profile, where the motion becomes the slowest towards the end. The damping factor ς determines how slowly the system slews-in on the terminal position. For $\varsigma = 0$ $\tan\phi$ is zero and the exponential term will be equal to one, so that the slew-rate profile will be symmetrical.

3.3. Time Histories of Slewing Functions

The time-histories of $f(t)$ and $\dot{f}(t)$ are shown in Fig. 3, for a damping factor of $\varsigma = 0.6$. The figure shows that the velocity is the largest mid-way, skewed towards the start of the operation, and decreasing towards the end. $f(t)$ reaches the peak value $f_{\max}$ at $t = T_{slew}$, which is the time at which $\dot{f}(t)$ is zero. It can be shown, by differentiating Eq.(10), that $\dot{f}(t)$ reaches a maximum at:

$$t_{\dot{f}_{\max}} = 0.5T_{slew}\left(1 - \frac{2\phi}{\pi}\right) \tag{11}$$

where the maximum $\dot{f}(t)$ is given by:

$$\dot{f}_{\max} = \frac{\pi}{T_{slew}} e^{-\left(\frac{\pi}{2}-\phi\right)\tan\phi} \cos\phi \tag{12}$$

It is clear from Eqs. (11) and (12) that for $\varsigma = 0$ $t_{\dot{f}_{\max}} = 0.5T_{slew}$ and $\dot{f}_{\max} = \pi / T_{slew}$. The time histories in Fig. 3 resemble the response of a well-designed servo-system, in which the slewed objects would have an actual mass or moment of inertia, and a proportional feedback law with position and rate feedback would reposition the object. The choice of this function greatly enhances the operator's impression that he, or she, is dealing with an actually existing physical system, rather than an abstract computer-generated scene which lacks the characteristics of the physical inertial world we are living in.

It should be noted however, that the implementation of the slewing function differs slightly from an actual servo system response. Following the overshoot and subsequent undershoot, the servo system output would settle on the final value of 1. The slewing function, however, is terminated at the peak-time, which is in this case at $t = T_{slew}$. Since the inclusion of the actual settling time response, following the peak value, would make the slewing process unnecessary longer, the slewing function was chosen to be terminated at $t = T_{slew}$.

Since computers are able to introduce viewing parameter changes in virtually zero time (e.g. the time needed for one background computation), slewing motions might appear to a system designer as unnecessary delay-introducing processes. However, discontinuities in the time-histories of viewing parameters are found to adversely affect spatial awareness and, in some cases, cause disorientation. The continuous slewing motion, however, allows the operator to actively 'follow' the viewing parameter change, from its initial setting to its final new situation. The association with a physically existing system which has distinct physical properties like mass or inertia, gives the operator the impression that the viewing parameter changes take place in a real physical environment, rather than an abstract computer-generated scene. By virtue of these slewing motions,

human characteristics, which are inherently present in the natural environment, can thus be utilized in the computer environment as well.

3.4. Determination of Slewing Parameter Values

A trade-off exists between the duration of the slewing process and the need for introducing natural viewing parameter changes. Too large slewing times might irritate the operator by introducing unnecessary delays in the process of setting viewing parameters. Too small slewing times might appear 'unnatural' and introduce disorientation. The choice of the slewing time would be the shortest time which still allows the operator to 'follow' the change along the way. Since larger changes demand larger slewing times, the slewing characteristics should be determined in terms of average slewing rates. These slewing rates however, should be expressed in screen coordinates, rather than real-world coordinates, since the actual stimuli associated with the slewing motions are perceived from the screen. Therefore the average slewing rates are defined either in degrees-per-second visual angle or pixels-per-second, measured on the screen.

3.4.1. Determination of the slewing time:

Prior to each viewing parameter change, the appropriate slewing time should be computed. For all viewing parameter operations the following process applies. The screen coordinates of a reference marker (in this case a manipulation pointer, discussed in detail hereafter), are computed for the 'old' and the 'new' viewing parameter setting. The distance between these coordinates, in pixels on the screen or degrees visual angle, is computed. The slewing time T_{slew} is chosen to be this distance, divided by the average slewing rate (in pixels-per-second or degrees-per-second, accordingly). The choice of the average slewing rate is highly empirical. Slewing rates in the range between 150-400 pixels-per-second are found to be adequate for all viewing system operations on a 20" diagonal monitor screen, measuring 1247 by 1024 pixels. However, this parameter should be fine-tuned for each operation individually through an experimental evaluation program.

Since small displacements take less time, a very small displacement is performed in almost zero time. This gives an erroneous impression of a 'jump'. Therefore, for the very small displacements, a minimum slewing time is defined. A value of 0.6 sec for the minimum slewing time is empirically chosen to be adequate for all viewing system operations.

3.4.2. Determination of the damping coefficient:

The choice of the damping coefficient ς is empirical as well. As mentioned earlier, ς introduces an asymmetrical velocity profile, where the system slows down towards the final position. The characteristic of the 'slowing down' towards the final setting is desirable, since it allows the operator to 'adjust himself to the new situation'. It also adds realism, by behaving like real physical servo systems, for which the slower motions towards the end are needed to achieve the necessary accuracy in the final positioning. On the other hand, too large values of ς will yield a too sluggish system. Adequate values are found in the range between $\varsigma = 0.6 - 0.8$. A slight adjustment of this parameter for each operation individually, might be necessary.

3.5. Manipulation Pointers

Requests for changes in the viewing parameter settings are introduced by pointers (also called 'handles'). These pointers are an integral part of the 3-D scene, i.e. they have a defined spatial position. The operator manipulates the pointers directly by selecting and dragging them with the screen cursor, slaved to the mouse. The motions of pointers are restricted to their allowed workspace. In addition, pointer motions are limited in magnitude in the sense that they can not be placed beyond the limits of the screen. This assures that the 'correspondence' between the new and the old setting will always be preserved. For example, a reversal of the viewing direction, which might lead to disorientation, will not be possible in one iteration.

3.6. Sequence of Operations

Manual viewing parameter operations are performed in four steps: (1) choosing the operation, i.e. translate, rotate or range; (2) selecting the appropriate pointer; (3) positioning the pointer at the required 3-D position; (4) executing the actual change by means of a controlled slewing motion. During this operation the pointer returns to its initial home position.

3.6.1. Choosing the operation:

Pop-up menus are used to select the required operation. The menus generally appear, when clicking the mouse button, while nothing is selected. The requested mode is initiated by choosing the appropriate menu item.

3.6.2. Selecting the pointer:

For each operation, appropriate pointers appear in the field. These pointers are discussed in detail hereafter. Selection of the pointer takes place by 'touching' the pointer with the screen cursor. It is not necessary to press the mouse button for selecting these pointers. Identical to the selection of all other objects on the display, the selected pointer will be highlighted (a change in color and an increase in line width will take place). By moving the screen cursor away from the pointer, the pointer will again become 'de-selected' and no changes will have taken place.

3.6.3. Positioning the pointer:

If a pointer is selected (appears with a bright color), and the mouse button is pressed and held down, the pointer will become *attached* to the cursor. This means that the pointer will follow the cursor, to the extent that the pointer motions remain within their allowed degrees-of-freedom. Thus, for example, the 'focus-of-interest' pointer can not leave the ground plane, the yaw-rotation pointer can only slide horizontally along the yaw-scale, etc. The cursor, on the other hand, will never be constrained in its motions and can be placed at any 2-D location, within the screen boundaries.

3.6.4. Enhancement of the screen cursor:

In order to ensure that the operator remains aware of the fact that he, or she, is actually manipulating the screen cursor, rather than, for example, the position pointer in the ground plane, it is essential to enhance the screen cursor during drag operations. This enhancement is achieved by enlargement of the screen cursor. The need for this

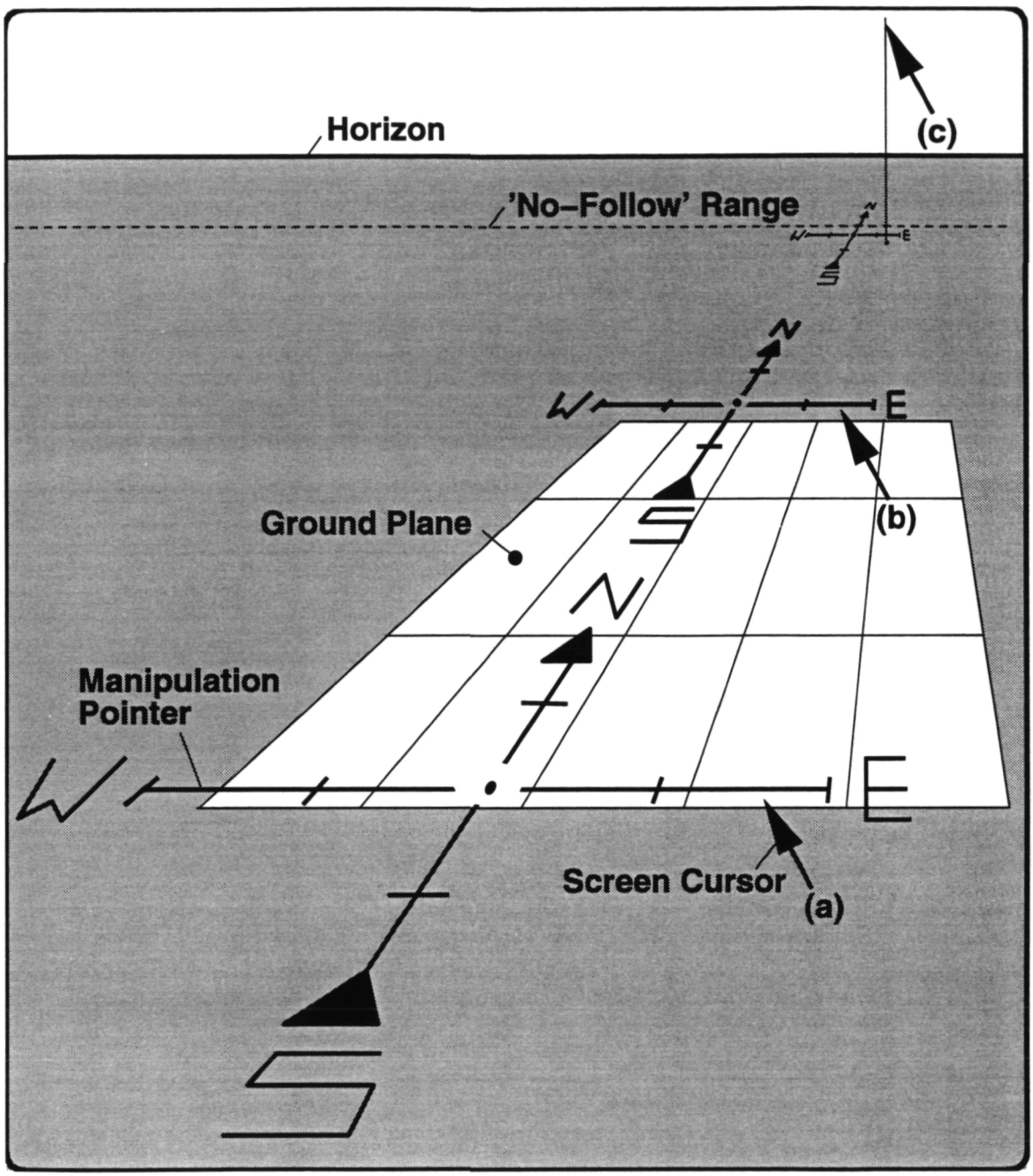

Figure 4.: Example of workspace restrictions of manipulation pointers

enhancement is demonstrated as follows. When the pointer and the cursor become attached to each other, it becomes less clear to the operator which one of the two is being manipulated. In case both the pointer and the cursor operate in the same 2-D workspace, e.g. for a position pointer, moving in the ground plane viewed straight from above, it doesn't really matter which one of the two is being manipulated by the operator, since the xy-motions of the mouse have an identical effect on each one of them.

However, in a perspective display, the workspace of a position pointer in the ground plane will be basically different from the workspace of the mouse. This is demonstrated in Fig. 4. Since the position pointer is constrained to the ground plane, it will not be possible to position it above the true horizon (for flat earth). The screen cursor, though, is not constrained and can be placed anywhere above the horizon. The solution to this problem is to constrain the workspace of the position pointer such that it remains within a given maximum 'no-follow' range, ahead of the actual 'point-of-interest'. In practice this means that the position pointer simply stops following the screen cursor, when it is requested to leave its workspace. Fig. 4 shows that the manipulation pointer remains 'attached' to the screen cursor in cases (a) and (b). However, in case (c) the screen cursor has reached the 'no-follow' range and the manipulation pointer remains within its allowable workspace. Note that the lateral motions of the pointer are not yet restricted. The way this is implemented is outlined in the next chapter.

3.6.5. Executing the requested change:

Execution of the change takes place by releasing the mouse button. A 'slew motion' is initiated during which the relevant viewing parameters are transitioned to the new requested values. In practice this means that the pointer will remain 'fixed' in the 3-D scene and slew back to its home position, following the changes taking place in the viewing parameters. The pointer thus constitutes a 'key reference point' during the transition to the new viewing parameter setting. The operator is able to see and follow the pointer along its path during the transition, which will contribute to his or her understanding of the operation and minimize the risk for disorientation. Since during the transition period the pointer constitutes the essential reference and since the operator has no control over the pointer, the less relevant screen cursor is blanked. After the slewing motion has been completed, the screen cursor will re-appear at the same position relative to the pointer, identical to the one before the start of the transition operation.

4

DESCRIPTION OF DISPLAY

4.1. Selection of Objects

All objects in the field (aircraft symbols, Air Traffic Control symbology, pointers, etc.) are subject to selection by the screen cursor. The motions of the screen cursor are unconstrained and have a fixed gearing with the 2-D control device (mouse). Objects are selected by touching them with the screen cursor. In all cases the system acknowledges that the object is selected, e.g. by changing its color, intensity, line width, etc. There is no need for pressing the mouse button in selecting objects. Apart from the acknowledgment of selection, no actions are taken by the system, provided the mouse button is not pressed. The object is de-selected by simply moving the mouse cursor away from the object.

Objects are arranged by object type, item and group. For example, all aircraft symbols belong to the group 'vehicle icons' and might be of various types, like 'heavy transport', 'light aircraft' or 'rotary wing'. A number of aircraft of the same type might be present in the area. Each individual aircraft is identified by an 'item' number.

Three levels of selection exist. The first level, full-body selection, takes place when the screen cursor touches any part of the object's body. The second level, selection by selection circle, takes place only when the screen cursor touches a circle, centered at the object. In the third level, the selection is disabled.

4.2. Menus and Menu Operations

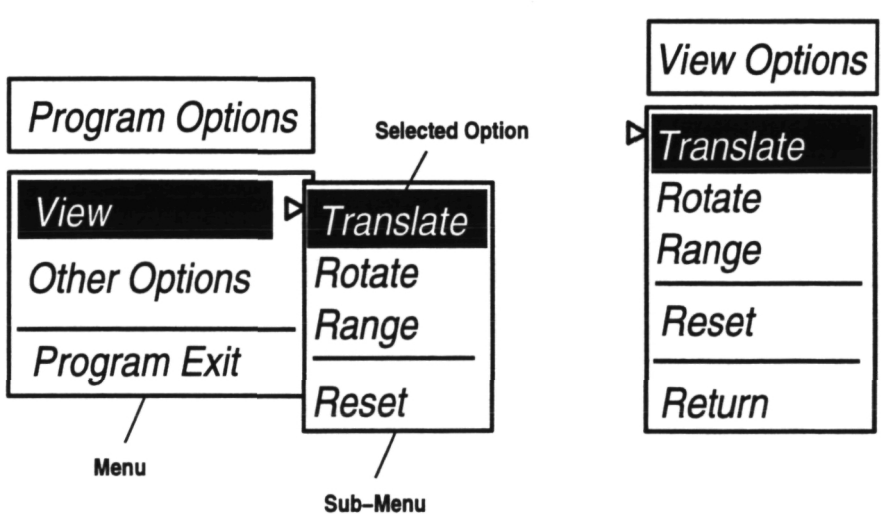

Figure 5.: Examples of pop-up menus

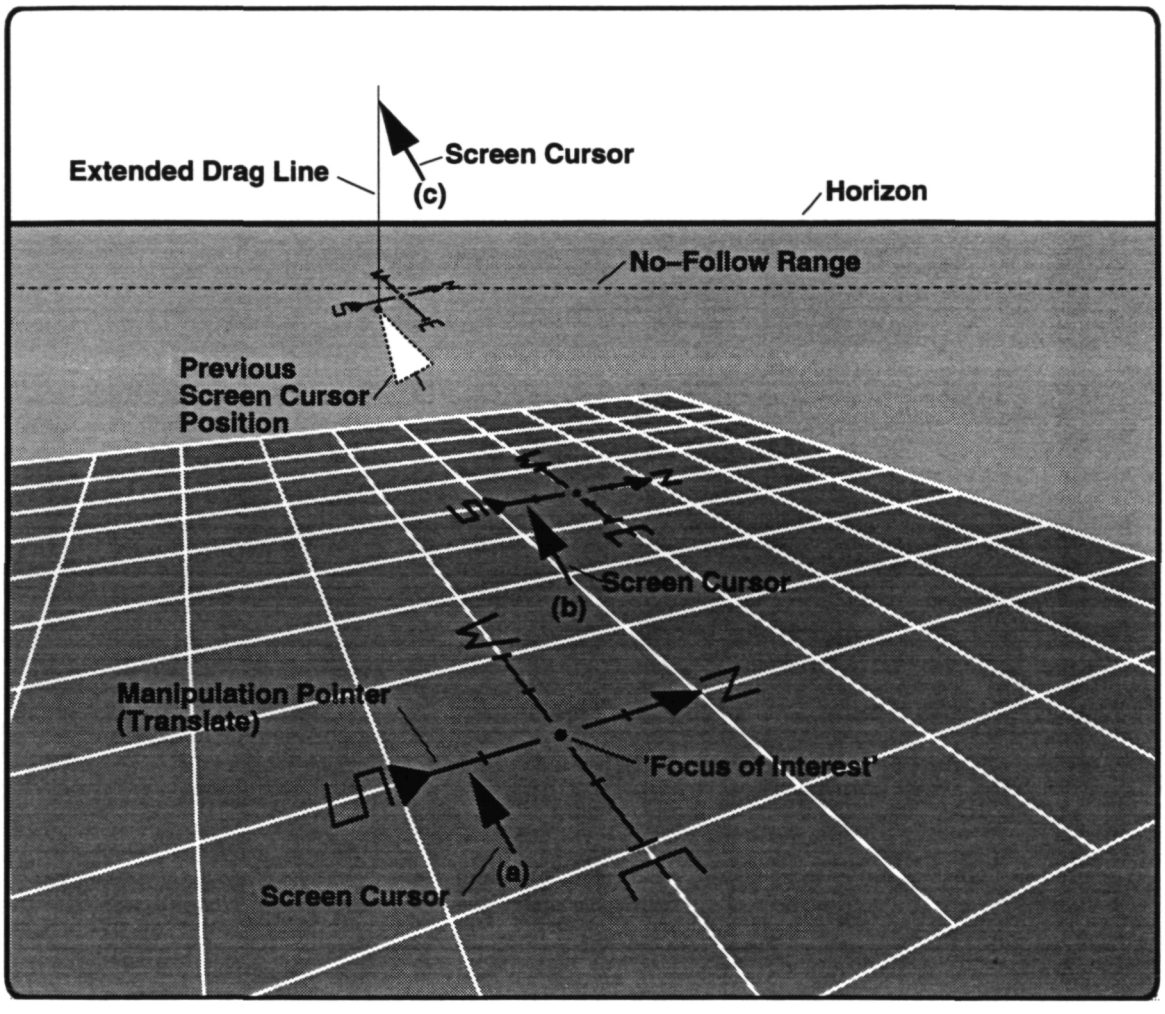

Figure 6.: Manipulation pointers for the translate mode

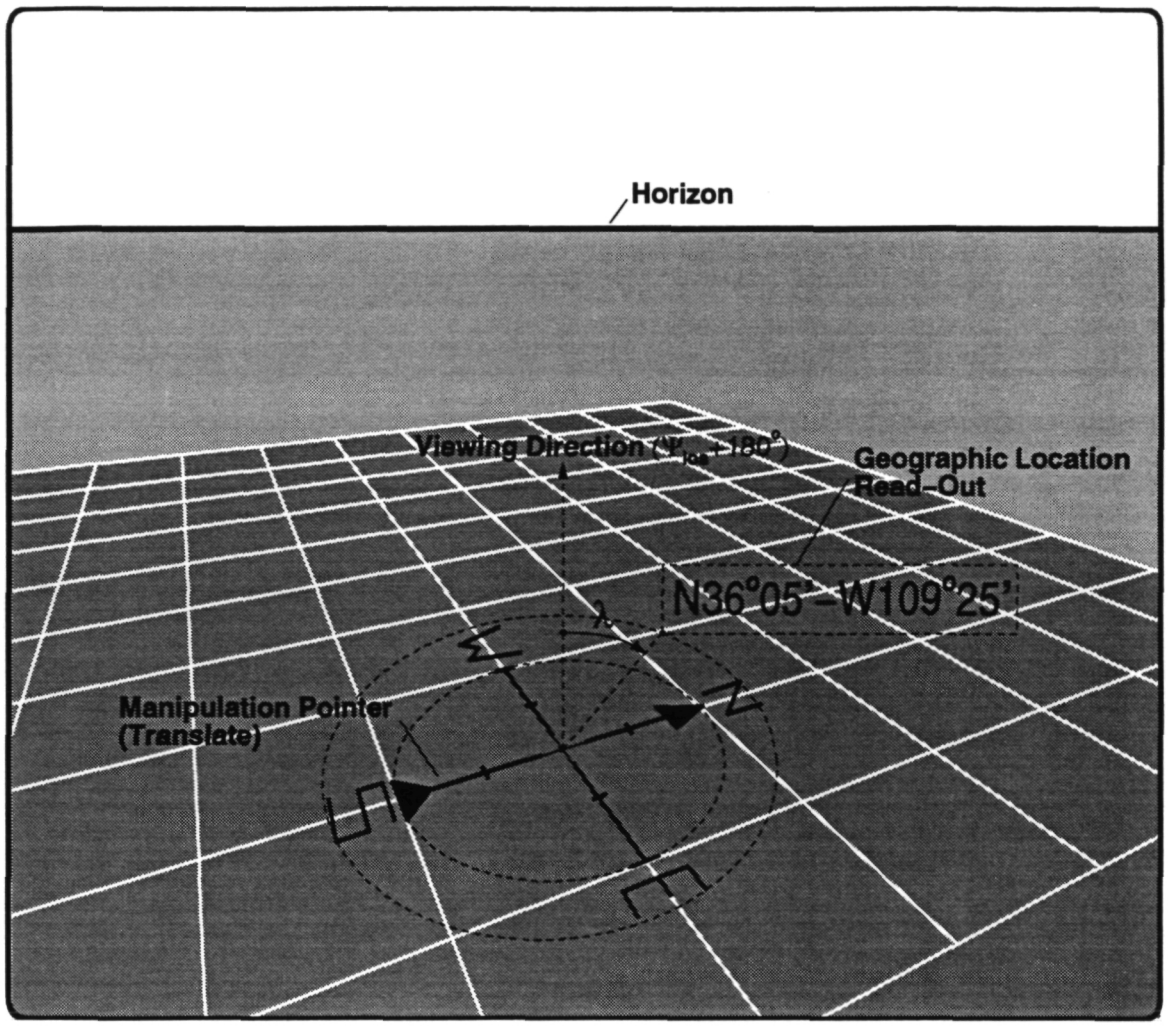

Figure 7.: Digital position read-out for the translate mode

The system modes are controlled through pop-up menus. Pop-up menus for controlling the system modes appear, when the mouse button is pressed, while no objects are selected. Task-specific pop-up menus will be used when the mouse button is pressed while a specific object is selected.

Examples of pop-up menus are shown in Fig. 5. The left menu appears in the main program mode, when the mouse button is pressed while no items are selected. Selection takes place by moving the screen cursor to the desired option and by releasing the mouse button. If the mouse button is released, while no selection has been made, the menu will remain visible. The menu of the main mode allows branching to other program modes and also includes the path for exiting the system. Certain selections might have sub-menus, such as the 'View' option.

The right menu appears, when in the Manual Viewing Parameter Setting (MVPS) mode and the mouse button is pressed while no objects are selected. The 'Return' option allows the return to the main program mode.

4.3. Manual Viewing Parameter Setting (MVPS) Operations

Each one of the three MVPS operations, i.e. translate, rotate and range, has specific manipulation pointers and reference scales associated with them. The general sequence of operations of selecting and positioning the pointers, and of executing the viewing parameter change, has been outlined in Section 3.6. Manipulation pointers are selected at a 'full-body' level, i.e. the selection takes place when any part of the pointer is touched with the screen cursor. In the repositioning phase, the pointer will remain attached to the screen cursor at the same 3-D relative position at which it was first touched by the screen cursor. The manipulation pointers for each one of the MVPS operations, are described in detail hereafter.

4.3.1. Translate mode:

The manipulation pointer for the translate mode is shown in Fig. 6 as a reference cross, on which the four wind directions are indicated. The center of the cross symbolizes the 'focus of interest' about which the viewing axis is rotated. The cross is located in the ground plane and drawn locally-level at all times, with the north-pointing arrow towards the north.

In this case the ground plane is represented by a flat surface. However, for non-flat structured 3-D terrain, the manipulation pointer should follow the contours of the terrain.

The cross is moved around the ground plane (or along the 3-D surface in case of non-flat terrain) by the screen cursor. It should be noted that although the motions of the screen cursor are slaved to the 2-D motions of the control device, the cross moves in 3-D space. Consequently, the cross will change, both in size and shape, as it is moved along the surface, see situation (a) and (b) in Fig. 6.

Since the cross symbolizes the position of an object in 3-D space, the operator might erroneously map the xy-motions of the control device into 2-D motions along the grid lines of the ground plane. This potentially confusing situation is avoided by enhancing the screen cursor during the relocation of the cross in the ground plane. The enhanced presence of the screen cursor will remind the operator that it actually is the screen cursor which is manipulated by the 2-D control device, rather than the cross itself.

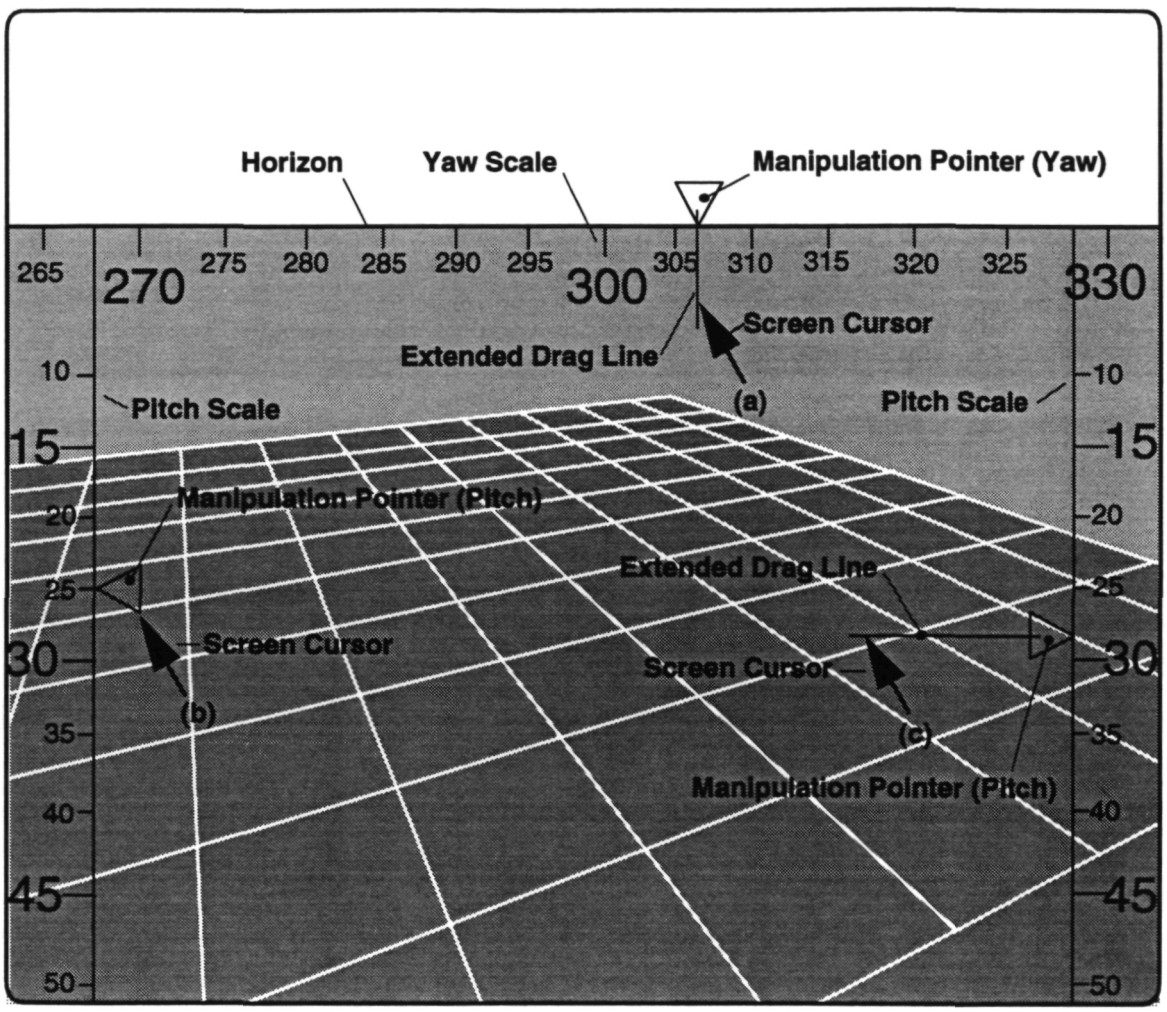

Figure 8.: Manipulation pointers for the rotate mode

As outlined in Section 3.6.4., the position pointer can not leave its allowed workspace. Thus, the pointer will not follow the screen cursor, if it would be required to cross the 'no-follow' range. This is demonstrated in Fig. 6 by situation (c). The screen cursor has moved above the dotted 'no-follow range' line. An extended 'drag line' appears, subtended between the cursor and the prior point of attachment. The pointer will still follow the cursor in the lateral motion, but not in the vertical one.

While moving the manipulation pointer on the screen, a digital read-out of the geographic location (in standard Earth latitude and longitude angular coordinates) of the pointer is displayed, as shown in Fig. 7. In order to avoid clustering of this information with the cross itself, the data string is positioned with its lower-left corner at the outer circle, enveloping the cross. The heading of this corner with respect to the center of the cross is obtained by adding the fixed angle λ to the viewing direction, in clockwise direction.

The actual change will be executed by means of a slewing motion, during which the pointer will be returned to its home position.

The actual size of the pointer in terms of units of length measured in the ground plane, is kept fixed during translate operations. However, this size is scaled according to the viewing range. Thus, if the ground plane were viewed straight from above, the size of the pointer in screen units, as it appears on the screen, would be unaffected by the viewing range. A similar scaling takes place for the slewing motions. Thus the slewing rate, in pixels per second, will be independent of the viewing range.

4.3.2. Rotate mode:

Manipulation pointers for the rotate mode are shown in Fig. 8. The pointer, moving along the horizontal yaw-scale located at the horizon, is used to set the azimuth angle of the viewing direction, i.e. the angle $\Psi_{los} + 180^{o}$. When the pointer is at rest, the numerical below the pointer indicates the viewing direction azimuth angle, measured clock-wise positive from the north.

The pointers moving along the vertical scales at the left and right sides of the display, are used to set the viewing elevation angle, i.e. the angle Θ_{los}. Also here, when the pointer is at rest, the adjacent numerical indicates the viewing elevation angle. For example, an angle of 90 degrees indicates that the ground plane is viewed perpendicularly.

The viewing parameter change is initiated by selecting the appropriate pointer, and by dragging it to the desired viewing azimuth or elevation. The actual change will take place by an appropriate slewing motion, during which the pointer will be returned to its home position.

The motions of the pointers are limited to their allowed workspace. Thus, the pointer for setting the viewing direction azimuth, can only move along the horizon. Situation (a) in Fig. 8 shows that the screen cursor has moved away from the horizon. Similarly to the position pointer, an extended drag-line will appear, which allows the pointer to follow the screen cursor, while staying on the horizon.

Situation (b) in Fig. 8 shows the extended drag line which appears when the screen cursor has moved away from the pitch scale.

Note that either one of the pitch scales can be used to set the viewing elevation angle. For example, when the elevation angle pointer in situation (c) is being repositioned, the right-hand pointer will remain centered at its home position.

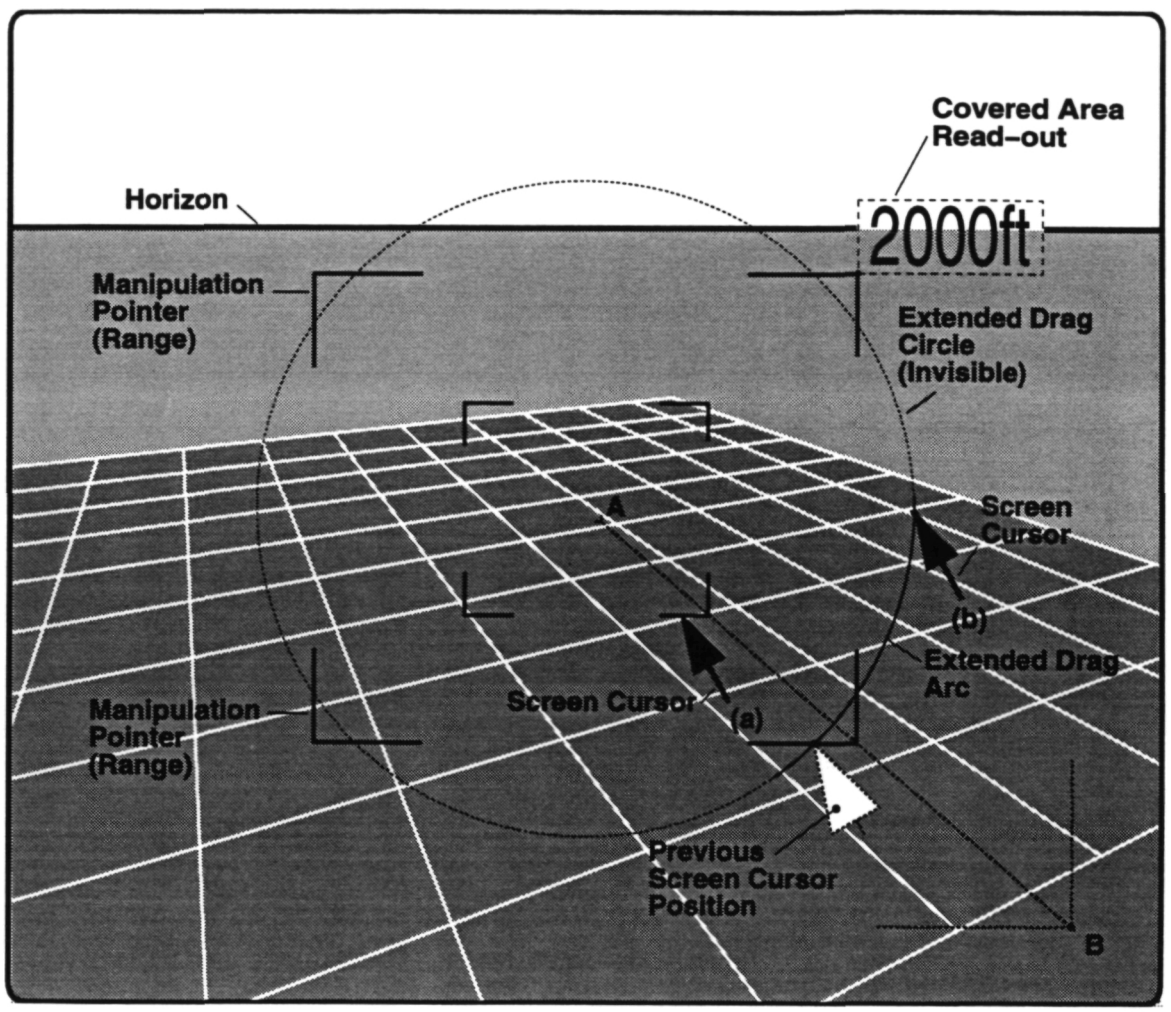

Figure 9.: Manipulation pointers for the range mode

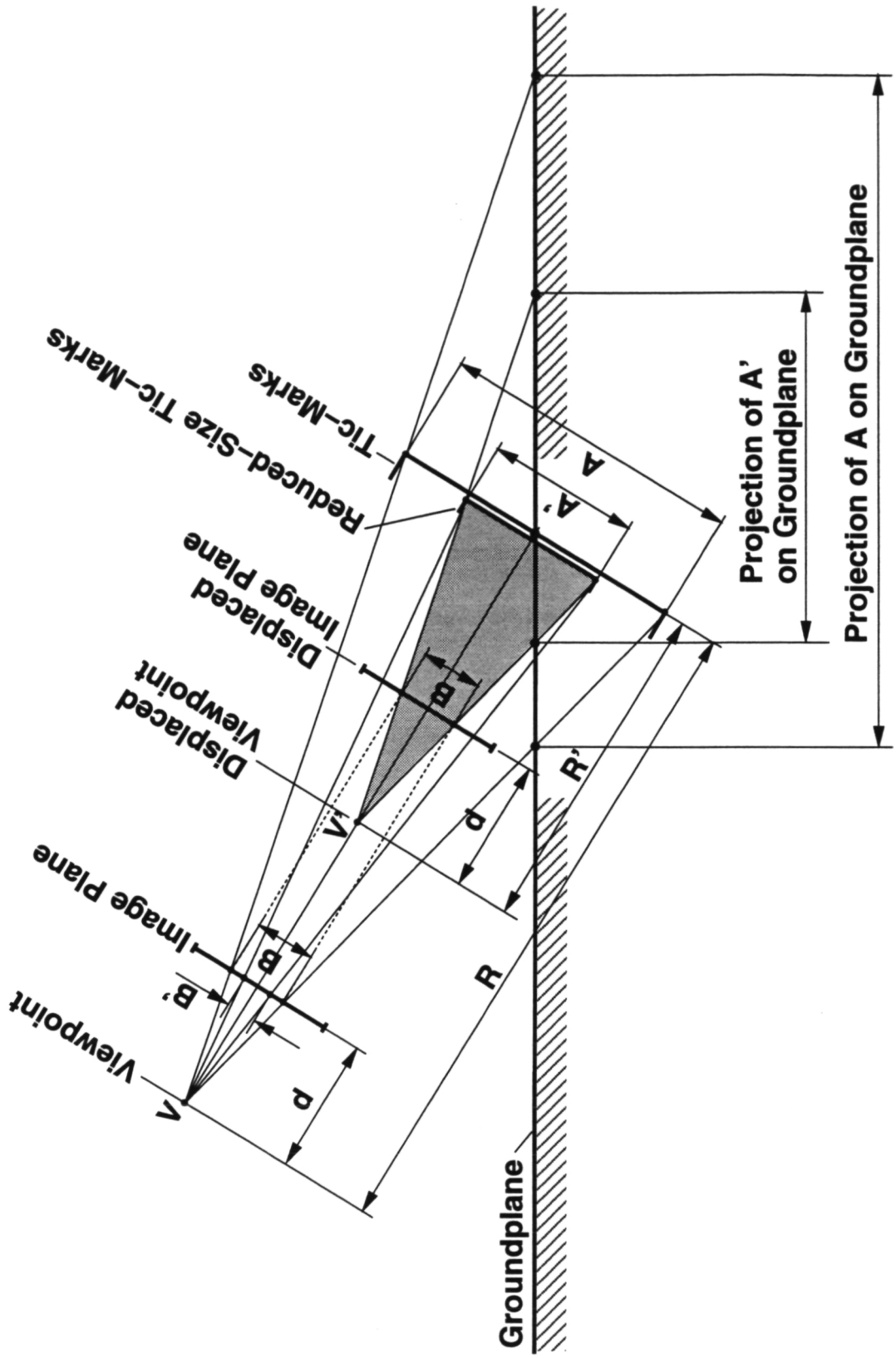

Figure 10.: Geometry of ranging operation

4.3.3. Range mode:

Manipulation pointers for the range mode are shown in Fig. 9 as the four tick-marks of a square. The ranging operation takes place by reducing or enlarging the area, closed-in by the tic-marks. The geometry of the ranging operation is shown in Fig. 10. The tic-marks are supposedly located in a plane perpendicular to the viewing vector, and centered at the focus of interest, as seen in Fig. 10. If the ground plane were viewed perpendicular, the tick-marks would enclose a rectangular area of given dimensions A. The size of the area enclosed by the tic-marks, as it appears on the image plane, is denoted by B.

The geometry of the ranging operation is shown in Fig. 10. The tic-mark area is reduced in size from size A to size A'. Consequently, size of the tic-mark area as it appears on the image plane, will be reduced as well, i.e. from B to B'. The change is executed by slewing the viewpoint V along the viewing axis, to its new location V'. Point V' is the location, at which the reduced tic-mark area A' will appear on the image plane at the same size B , as it had before the change. The ranging operation is thus also consistent with the other viewing parameter operations in the sense that at the completion of the execution of the change, the manipulation pointers have returned to their home position.

Selection takes place by touching any one of the four corner tic-marks with the screen cursor. Situation (a) in Fig. 9, shows the screen cursor attached to the lower-right tic-mark. Since the tic-mark area can only be reduced or enlarged in size, i.e. it can not be reshaped, the workspace of the tic-mark of situation (a) is restricted to motions along the dotted line, subtended between points A and B, (points A and B are the 'no-follow' limits). The motion of the other three tic-marks will be such, that the original shape of the tic-mark area will be maintained.

Situation (b) in Fig. 9 shows that the tic-mark area has been enlarged. However, the screen cursor has also moved away from the allowed tic-mark workspace. Similar to the position and rotate pointers, an 'extended drag arc' appears (a section of the dotted circle), which allows the pointer to follow the screen cursor, while remaining on the dotted line, i.e. while staying within its allowed workspace.

While moving the manipulation pointer on the screen, a digital read-out of the width of the covered area is displayed, as shown in Fig. 9. This value is in fact the width of the tic-mark area on the ground plane, if the ground plane were viewed perpendicular. The data string is centered with its lower-left corner at the upper-right tic-mark.

4.3.4. Reset and return options:

As mentioned earlier, reset and return operations are initiated through the 'View Options' menu. This menu appears while in the MVPS mode, and no pointers are selected. The 'Return' option returns the system to the mode from which the MVPS mode was initiated, i.e. here the main program mode.

The 'Reset' option will allow the viewing parameters to be reset to a given initial setting, or preferred viewing situation.

5

CURRENT AND PLANNED ACTIVITIES

5.1. Automated Viewing Parameter Setting (AVPS)

Current efforts deal with the development of automated viewing parameter setting schemes. These schemes employ an optimization strategy, aimed at identifying the best possible vantage point, from which the Air Traffic Control scene can be viewed, for a given traffic situation. The scheme is intended to contribute to overall system performance in the following manner:

1. It directs the operator's attention to critical areas in the field, by viewing these areas centrally and from a nearby distance, while at the same time maintaining a global view over large, less critical areas, by viewing these areas from far away in the periphery.

2. It prevents clutter, or exclusion from the view, of one aircraft symbol by another one, by modifying the viewing parameters such, that each one of the aircraft in the critical area appears separated from the other.

3. It finds a compromise between the accuracy, at which horizontal and vertical relative positions can be estimated, e.g., a plan view provides the best horizontal relative position information, but does not provide relative vertical position information, whereas the opposite is the case for a side view.

5.2. Design Requirements for AVPS Operations

Basic design requirements for AVPS operations are:

1. AVPS activities are initiated only when absolutely necessary. This will require the definition of threshold values, below which AVPS activities are not initiated.

2. AVPS activities are executed intermittently. This will require the definition of a minimal allowed time-span between operations. The intermittent operation will give the operator the impression of viewing the scene mostly from a stationary viewpoint, with occasional, short-lasting changes. This will allow the operator to differentiate between motions of objects in the field, and motions due to the viewing parameter changes.

3. AVPS activities are subject to limitations in magnitude of viewing parameter changes. Typically, changes, exceeding the ones which would occur in manual viewing parameter setting (MVPS) operations, will not be allowed.

4. All AVPS activities are executed by slewing motions, identical to the ones of the MVPS system.

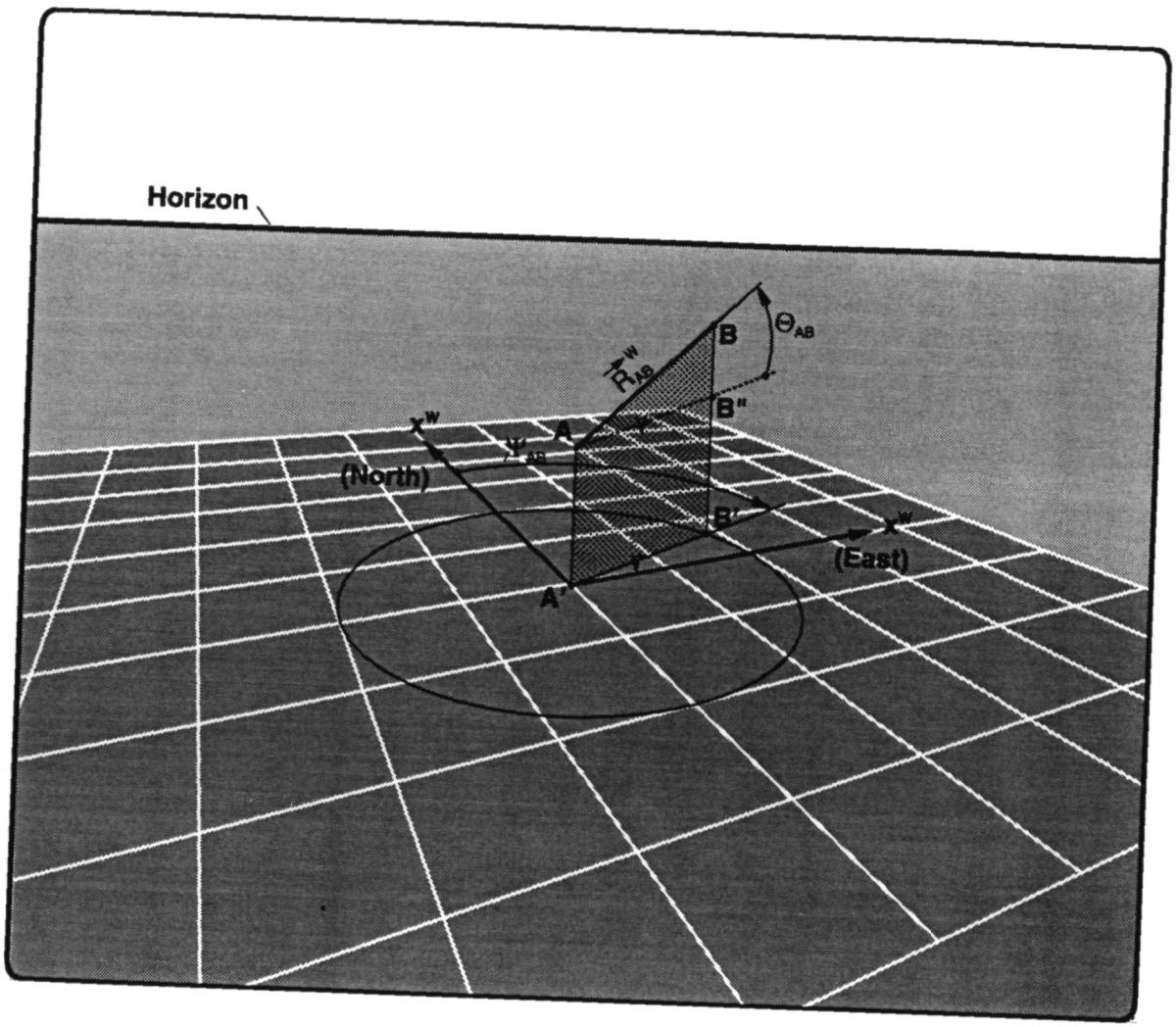

Figure 11.: Perspective view of two spatially separated aircraft

5. The operator must have the authority to override the AVPS activity manually at all times, i.e. stop a certain activity in the middle, return to a previous setting, etc.

6. MVPS operations will be possible also when the AVPS system is engaged. Thus, MVPS activities will take priority over AVPS operations. AVPS activities will resume a minimal allowed time-span after the MVPS activity has been completed and use the new setting as the baseline for their computations.

5.3. Principle of Operation of the AVPS

The AVPS algorithm is based on the minimization of a global cost function J. This global cost is composed of two parts: J^1 and J^2. The first part, J^1, relates to the location on the image plane, at which the aircraft symbols appear. For example, a large cost should be attributed to aircraft which should be given a high level of attention and which should appear in the center of the display, but which are actually displayed far-off to the side. Minimizing the first part of the cost would mean choosing viewing parameters which would tend to move these aircraft to the center of the display.

The second part, J^2, comprises the sum of all individual costs associated with the relative spatial position of each individual aircraft with respect to its neighbor. This individual cost should reflect how well the operator is able to estimate the relative spatial positions between the two aircraft. In principle, an individual cost should be associated with each possible pair of aircraft in the area. This means that if the total number of aircraft is N, the number of individual pairs to consider is $0.5(N^2 - N)$. A preliminary course selection might reduce this number drastically, e.g. it will not be necessary to include the individual cost of pairs, of which the aircraft are far apart.

The optimization problem is defined as follows:

> *Find the viewing parameter setting, (2 translational, 2 rotational, and 1 ranging parameter), subject to the constraints set by magnitude of change limitations, which minimizes the global cost function J.*

5.4. Estimation of Spatial Position Between Aircraft

5.4.1. Geometry of the 3-D situation:

Fig. 11 shows the perspective view of two aircraft A and B, separated spatially, both in horizontal position and in height. The vector $\vec{R}_{AB}^{W}$, expressed in the World Coordinate System W, describes the position of aircraft B with respect to A. The length of this vector, $R_{AB} = \left\| \vec{R}_{AB}^{W} \right\|$, is the distance between the two aircraft. The projections of A and B on the ground plane are A' and B'. The azimuth of B with respect to A is the angle Ψ_{AB} subtended between the line $A'B'$ and the axis x^W pointing to the north. The elevation of B with respect to A is the angle Θ_{AB} subtended between the line AB and the line AB'', parallel to the line $A'B'$ in the ground plane. Due to the perspective view, the angles Ψ_{AB} and Θ_{AB} appear distorted and are estimated usually larger or smaller than their actual value, as shown in Ref. 1. The errors in estimating the angles Ψ_{AB} and Θ_{AB}, as well as in estimating the range R_{AB}, are a function of the viewing parameters. Functional relations

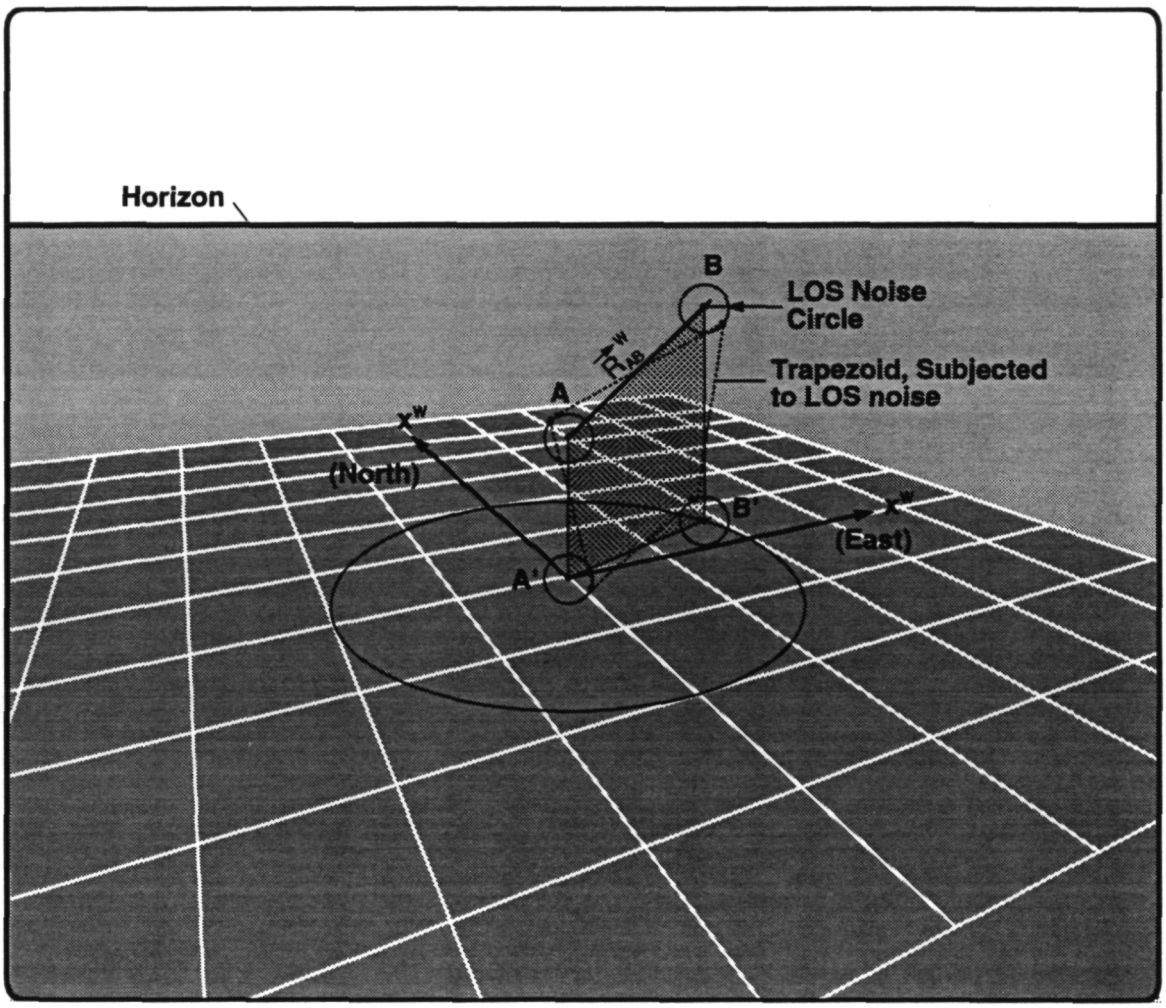

Figure 12.: The effect of line-of-sight noise on spatial estimates

between these errors and the viewing parameters have been investigated experimentally and analytically in Ref. 1.

It is clear that the angle Ψ_{AB} is best estimated, when the scene is viewed straight from above, i.e. a plan view. However, in that case the angle Θ_{AB} can not be estimated, i.e. the error in estimating Θ_{AB} becomes infinitely large. On the other hand, Θ_{AB} is best estimated when the observer's eye is located in the ground plane and the viewing axis is perpendicular to the plane $ABB'A'$, but then the error in estimating Ψ_{AB} might become very large.

5.4.2. Cost associated with estimation errors:

A cost can be associated with the errors in estimating the angles Ψ_{AB} and Θ_{AB}, and the range R_{AB}. This cost should reflect the expected error in the estimation of these variables. Thus, the cost should grow when the estimation errors are expected to be large.

Rather than associating a cost with the errors in estimating the angles Ψ_{AB} and Θ_{AB}, it is more meaningful to associate a cost with the errors in estimating the vector $\vec{R}_{AB}^{W}$. The components of $\vec{R}_{AB}^{W}$ are given by:

$$\vec{R}_{AB}^{W} = \vec{x}_{B}^{W} - \vec{x}_{A}^{W} = \begin{bmatrix} x_{B}^{W} - x_{A}^{W} \\ y_{B}^{W} - y_{A}^{W} \\ z_{B}^{W} - z_{A}^{W} \end{bmatrix} \tag{13}$$

where $\vec{x}_{B}^{W}$ and $\vec{x}_{A}^{W}$ are vectors, describing the position of aircraft B and A in the W system. If the errors involved in estimating the vector $\vec{R}_{AB}^{W}$ are given by the error vector $\vec{\varepsilon}_{R}^{W} = \left\{ \varepsilon_{R_x}^{W} \quad \varepsilon_{R_y}^{W} \quad \varepsilon_{Rz}^{W} \right\}^{T}$, the cost, associated with the error in estimating the relative spatial orientation of aircraft pair AB could be formulated as:

$$J_{AB}^{2} = \frac{(\varepsilon_R)^2}{(R_{AB})^2} \tag{14}$$

where $\varepsilon_R = \left\| \vec{\varepsilon}_{R}^{W} \right\|$ denotes the length of the error vector.

In Ref. 1 a model for spatial orientation by familiarity cues has been developed and experimentally evaluated. This model is able to compute the error vector $\vec{\varepsilon}_{R}^{W}$ for each aircraft pair and viewing parameter setting. These computations are based on spatial, 3-D matching of the vertices of the trapezoid $ABB'A'$ to their corresponding perceived lines-of-sight. The model uses familiarity cues, based on a priori knowledge of the 3-D shape of the object, e.g. it utilizes the knowledge that the lines projecting on the ground plane, are parallel, that these lines are perpendicular to the ground plane, etc.

The model is based on the assumption that the inaccuracies, which exist in the perception of the lines-of-sight of the vertices of the trapezoid, are the main source of error in estimating the vector $\vec{R}_{AB}^{W}$. This is demonstrated in Fig. 12. The line-of-sight vector is corrupted by a noise vector of a constant magnitude, and located in a plane perpendicular to the line-of-sight. The in-plane angle, determining the orientation of this

noise vector, is distributed uniformly between zero and 360 degrees. The noise-corrupted line-of-sight vectors thus intersect the image plane at points located on the circles, centered at the trapezoid vertices. In the example of Fig. 12, the dotted, deformed trapezoid constitutes the input shape, on which the 3-D matching scheme is employed. Obviously, this deformed shape will lead to errors in the estimation of $\vec{R}_{AB}^{W}$. For each aircraft pair and each viewing parameter setting, the error vector $\vec{\varepsilon}_R^W$ is computed by a Monte Carlo method, in which the in-plane angles of the noise vectors are varied randomly. For a sufficiently large ensemble, the numerator of Eq. (14) will be the expected value: $E\left\{(\varepsilon_R)^2\right\}$, which is the power of ε_R.

If the line-of-sight noise vector magnitude is considered to be constant, the error vector $\vec{\varepsilon}_R^W$ is a function of five parameters. Two parameters are needed for defining the angular orientation of the trapezoid $ABB'A'$ with respect to the line-of-sight to point A' [3]. Three additional parameters comprise the normalized dimensions of the trapezoid, i.e. the distances AA', BB' and AB, normalized with respect to the range measured along the line-of-sight to point A'.

It is impractical to employ the spatial orientation model for each aircraft pair and a variety of viewing parameter settings in real time. Fortunately, the experimental results of Ref. 1 have indicated, that the expected value of $(\varepsilon_R)^2$ can usually be modeled in terms of relatively simple trigonometric functions of the parameters determining the angular orientation of the trapezoid $ABB'A'$ with respect to the line-of-sight to point A'. The weighting coefficients, multiplying these trigonometric functions, depend on the shape of the trapezoid in 3-D space (not on the image plane), i.e. the normalized distances AA', BB' and AB. The spatial orientation model can be used to compute these weighting coefficients in real-time, and store them in a look-up table.

Thus, although the computation of $E\left\{(\varepsilon_R)^2\right\}$ by means of the model is complex and time-consuming, the use of trigonometric functions and retrieval of pre-computed data, might reduce this computation to a limited number of simple arithmetic operations, which might be easily realized in a real-time framework.

5.5. Computation of the Global Cost

The first part of the global cost, i.e. the cost J^1, being the cost relating to the area on the image plane at which the aircraft symbols appear, is computed as follows. Each point of the image plane surface is rated according to its distance from the central viewing area. The individual cost associated with aircraft A is given by:

$$J_A^1 = \frac{p_A}{r(x_s, y_s)} \tag{15}$$

where P_A is a value associated with the level of attention which should be given to the aircraft. For example, aircraft in danger of violating minimal separation distances, should be given a high level of attention.

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[3] These parameters will actually determine the shape of the trapezoid, as it will appear on the image plane. A third parameter, e.g the 'twist' about the line-of-sight to the point A', will have no effect on the apparent shape of the trapezoid on the image plane, and thus also not on the errors.

The image plane surface rating $r(x_s, y_s)$ reflects the 'real estate' value of the screen location. It is important in realizing the optimization scheme, that this function should be continuous. Central locations are rated high and off-center locations are rated low. It should be noted that a small rating, different from zero, should be associated to areas *outside the* screen boundaries as well. This will assure that aircraft, demanding a high level of attention but outside the screen boundaries, will be moved into the visible range. The cost J^1 is computed by summing the individual costs given by Eq. (15), for all aircraft.

The second part of the global cost, i.e. the cost J^2, reflecting how well the operator is able to estimate the relative spatial positions between two aircraft, is the weighted sum of the costs associated with each one of the aircraft pairs, according to:

$$J^2 = \sum_j c_j J_j^2; \quad j = pair(A,B); pair(A,C); \cdots etc. \tag{16}$$

where the weighting factor c_j, by which each one of the individual costs is multiplied, is a function of the level of attention which should be given to the particular aircraft pair. For example, an aircraft pair which appears 'clustered' on the display, will have a high value of J_j^2. If also the required level of attention is high, i.e. c_j is large as well, the pair will have a high impact on the cost J^2, so that the optimization scheme will seek a solution which will attempt to 'de-cluster' the aircraft. However, if c_j is zero, the clustered aircraft pair will be ignored by the scheme.

5.6. Impact of Individual Aircraft on the Global Cost

It should be noted that although the global cost reflects a measure of the average performance of a large number of aircraft in the area, the optimization scheme will still be sensitive to display anomalies occurring with one single aircraft, or one single pair of aircraft.

For example, for aircraft outside the boundaries of the screen, the surface rating $r(x_s, y_s)$ in Eq. (15) will be very small and, provided P_A is non-zero (i.e. the aircraft should actually be visible), J_A^1 will be large and have a large impact on the global cost. Similarly, for an aircraft pair of which the vector $\vec{R}_{AB}^W$ can not be properly estimated, the error vector $\vec{\varepsilon}_R^W$ will be very large, and provided the weighting coefficient c_{AB} is non-zero (i.e., it is important that the operator is aware of aircraft pair AB its relative orientation), the term $c_{AB}J_{AB}^2$ will be large and have a significant impact on the global cost. In both cases the optimization scheme will seek a solution which will reduce the large individual costs, thus correcting display anomalies occurring with individual aircraft.

5.7. Optimization Method

A common numerical gradient method, limited search method, steepest descend method or a Newton-Raphson second-order scheme will be attempted to solve the optimization problem. The use of predetermined motion patterns might be necessary to limit the degrees-of-freedom and reduce the complexity of the search for a minimum. A

design requirement is that the computations should be completed in a time-span which is one order of magnitude less than the time required to execute the viewing parameter change (through a slewing motion).

5.8. Current Status of Activities

The MVPS system has been implemented in a generic framework for an Air Traffic Control display. The software has been written for a Silicon Graphics, Indigo II system. It includes indirect control over the viewing parameters by manipulation pointers, as outlined in Chapter 4. The changes are executed by appropriately tuned slewing functions. The framework has the flexibility to include a large database of aircraft, terrain features and air-route maps and symbology. This system is being augmented with the AVPS system, and will constitute the basic framework for performing partial, or full-scale, operator-in-the-loop experiments.

Present activities include the formulation of the cost functions, image plane surface rating function $r(x_s, y_s)$, level of attention function P_A, the expected value $E\{(\varepsilon_R)^2\}$ function, and the various weighting coefficients, to be used in the AVPS scheme. A preliminary version of the system is expected to be completed in the coming month. The aircraft database are being included, and a sensitivity analysis are being performed, in order to determine the sensitivity of the various cost function items to changes in viewing system parameters.

It is being investigated in particular, whether and to which extent, cost function items are sensitive to typical perspective display singularities such as visual exclusions or ambiguities. Other tests include sensitivity of the cost function to changes in the level of required attention.

The results of this sensitivity analysis will determine the optimization scheme, which will be employed. The performance of the system will be tested in terms of its robustness to numerical instabilities, convergence to meaningful solutions, and its time required for one computation cycle. The use of predetermined motion patterns will be explored, in case complexity of the search for an optimum demands the reduction of the degrees-of-freedom.

5.9. Planned Activities

5.9.1. Analytical tests:

A wide range of analytical tests will be carried out to test the validity of the approach and to evaluate its performance. The ability of the AVPS system will be investigated in solving anomalies in the perspective representation, i.e. occlusions, ambiguities, etc. Furthermore, the response of the AVPS system to changes in the level of required attention will be investigated for a wide range of conditions.

5.9.2. Operator-in-the-loop experiments:

During the summer 1995 a series of operator-in-the-loop experiments will be conducted to validate the system and to evaluate its effectiveness. These experiments will include abstracted, part-task experiments and full-task experiments.

Part-task experiments will concentrate on the ability of the operator to estimate spatial locations and orientations from the display. At first it will be investigated whether the viewing parameter setting suggested by the AVPS system, will yield smaller errors in the judgment of the relative positions between aircraft. This will be done by having the subject make the same judgment twice: once for a condition in which the global cost is high, and once when this cost has been brought to a minimum. In this experiment the subject will have no control over the viewing parameter setting, and 'static' viewing conditions will be used. (Note that slewing motions might improve spatial awareness, by adding motion cues). The conditions will be randomly accessed, have at least four repetitions, and the subject will be ignorant about the purpose of the experiment.

In a subsequent part-task experiment it will be investigated how meaningful the solutions of the AVPS system are to the operator. This will be done by repeating the previous experiment with the difference that the subject now has control over the viewing parameters by means of the MVPS system. The solutions of the AVPS system can be considered 'meaningful', when MVPS activity for situations with a low global cost, is much smaller than the one for situations with a high global cost.

Full-task experiments will study the performance of the operator when the AVPS system is enabled or disabled. In both cases, the operator still has control over the viewing parameters through the MVPS system. Performance will be measured in terms of his abilities to carry out the controller's task, i.e. early detection of possible separation conflicts, spatial awareness, etc. Subjective ratings, like a 'handling qualities' scale, might be used as well.